PARSONS ENGINEERING SCIENCE

A UNIT OF PARSONS INFRASTRUCTURE & TECHNOLOGY GROUP INC.

DCE-9

BACKGROUND CHARACTERIZATION OF THE RESPONSE OF GEOPHYSICAL SENSORS FOR SUBSURFACE UXO DETECTION

Prepared For:

U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

Prepared By:

PARSONS ENGINEERING SCIENCE, INC.

FAIRFAX, VIRGINIA

JANUARY 1997

PARSONS ENGINEERING SCIENCE, INC.

10521 Rosehaven Street • Fairfax, Virginia 22030 • (703) 591-7575 • Fax: (703) 591-1305

January 7, 1997

Dr. Ernesto Cespedes
US Army Engineer Waterways Experiment Station
Environmental Laboratory
Environmental Sensing Branch
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Subject: Background Characterization of the Response of Geophysical Sensors for Subsurface UXO Detection
DACA39-96-M-1957
Submittal of Final Report

Dear Dr. Cespedes:

Parsons Engineering Science, Inc. (Parsons ES) is pleased to submit two copies of the Final Report for Contract DACA39-96-M-1957, Background Characterization of the Response of Geophysical Sensors for Subsurface UXO Detection. This report documents the field demonstrations of the EM61 0.5-m coil and the EM61-3D at the Fort A.P. Hill, Virginia and Fort Carson, Colorado test sites that were conducted as a part of Phase I of the above referenced study.

Parsons ES would like the opportunity to analyze our data and meet to compare our results with DARPA's selections. Scoring first in the Jefferson Proving Ground Phase II test, we feel that this would be very beneficial to DARPA's report. We also have several other ideas that Scott Sauchuk and I would like to pursue with you in the near future.

Parsons ES greatly appreciated this opportunity to work with WES and DARPA on this most challenging project. We look forward to the possibility of continuing this relationship in the future. Please contact me at (703) 218-6288 if you have any questions or comments.

Very truly yours,

Robert A. Menke, P.E.
Senior Associate

RAM:lsp
G:\JOBS\730\730268\BM7002LP.LTR

cc: V. George

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LIST OF ACRONYMS

cm	Centimeter
DARPA	Defense Advanced Research Projects Agency
EM	Electromagnetic
Hz	Hertz
IDA	Institute for Defense Analysis
ms	Milliseconds
NVESD	Night Vision Electronic Sensors Directorate
Parsons ES	Parsons Engineering Science, Inc.
TDEM	Time Domain Electromagnetic
UXO	Unexploded Ordnance
WES	U.S. Army Engineer Waterways Experiment Station

Identification of Responsible Personnel

The following individuals at Parsons Engineering Science, Inc. had significant, specific input into the preparation of this document:

NAME	**TITLE**
Robert Menke, P.E.	Parsons ES, Project Manager
Scott Sauchuck, P.G.	Parsons ES, Geophysicist
Josh Bowers, P.G.	Parsons ES, Geologist
Lanette Pickeral	Parsons ES, Project Coordinator
Ernesto Cespedes	Waterways Experiment Station, Project Manager
Dwayne Butler	Waterways Experiment Station
Vivian George	Defense Advanced Research Projects Agency
Thomas Altshuler	Institute for Defense Analysis

SECTION ONE

INTRODUCTION

1.1 INTRODUCTION

Parsons Engineering Science, Inc. (Parsons ES) was contracted by the U.S. Army Engineer Waterways Experiment Station (WES) to perform time-domain electromagnetic (TDEM) surveys at two sites. The TDEM surveys were conducted as a part of a study on the background characterization of the response of geophysical sensors used for subsurface unexploded ordnance (UXO) detection. This study was sponsored by the Defense Advanced Research Projects Agency (DARPA) in conjunction with WES, Institute for Defense Analyses (IDA), Walcoff and Associates, and Night Vision Electronic Sensors Directorate (NVESD).

1.2 PURPOSE

1.2.1 The study on the background characterization of the response of geophysical sensors for subsurface UXO detection was divided into two phases: data collection (Phase I) and data analysis (Phase II). Parsons ES and six other companies were selected to participate in Phase I. The purpose of Phase I was to acquire data with a variety of sensors that span the range of UXO and landmine detection technology.

1.2.2 This report presents a discussion on the two geophysical sensors selected and the field procedures followed by Parsons ES during the Phase I TDEM surveys at Fort A.P. Hill, Virginia and Fort Carson, Colorado. This report also documents the data acquisition methodology used by Parsons ES during Phase I of the study; however, the report does not present an interpretation of the data collected from the Fort A.P. Hill, Virginia and Fort Carson, Colorado test sites.

1.3 OVERVIEW OF THE TDEM SURVEYS

1.3.1 Parsons ES used the 2-channel Geonics EM61 (0.5-meter coils) and the 60-channel EM61-3D sensors to conduct TDEM surveys at four test grids. The test grids were equally divided between two test sites: Fort A.P. Hill, Virginia and Fort Carson, Colorado. The test sites were located within two physiographically distinct areas. The two test grids at Fort A.P. Hill, Virginia (Firing Point 20 and Firing Point 22) were located in a moist climate. Whereas, the two additional grids at Fort Carson, Colorado (Seabee and Turkey Creek) were located in a dry climate. Soil types, conditions, and the amount of metallic debris varied widely at each site.

1.3.2 Each of the four test grids, two at each site, was a rectangular grid oriented with survey lines along magnetic north. The grids were 100 meters wide north to south and 125 meters long east to west; however, Firing Point 22 at Fort A.P. Hill was extended to the east to avoid a muddy portion in the center of the rectangular grid. All data were acquired along north-south survey lines. In accordance with convention, the origin of the local grid was located in the southwest corner (0E, 0N), and *east* and *north* are considered positive directions.

1.3.3 The test grids consisted of designated strips running from 0N to 100N. The standard site layout and associated terminology is as follows:

- Blue Side Bar (0E-5E);
- Red Calibration Lane (8E);
- Yellow Side Bar (11E-14E);
- Center Square (15E-115E); and
- Orange Side Bar (120E-125E)

1.3.4 Various UXO, landmines and objects of simple geometric shapes (e.g., spheres, square plates, and circular disks) were buried at known depths and orientations within the side bars. The location and identity of objects planted from 0N to 30N in the blue, red, and yellow side bars were provided to the contractors to assist in the calibration of their equipment. Five sets of registration objects were buried in the center square to verify the accuracy of the coordinates assigned to the sensor data.

1.3.5 During Phase II of this study, personnel from IDA and the Applied and Computational Mathematics Program at DARPA will analyze the data obtained from all sensors. The main objective is to develop algorithms that substantially reduce the false alarm rate without sacrificing detection capabilities. Discrimination and sensor fusion technology will be emphasized. Finally, the data collected during this program will be made available to sensor developers, researchers and other parties interested in improving and developing detection technology.

SECTION TWO

DESCRIPTION OF SENSORS

2.1 EM61

2.1.1 Parsons ES utilized the Geonics EM61 for the test demonstrations at Fort A.P. Hill and Fort Carson. The EM61, which is a time-domain metal detector, consisted of a coil assembly for transmitting and receiving electromagnetic (EM) fields, a backpack with battery and electronics, and a datalogger. The EM61 transmitted a primary magnetic field in the form of a repetitive step or ramp signal. The abrupt termination of this primary field caused a secondary field to be induced within the nearby conductors. The secondary field induced in the relatively resistive soil decayed rapidly, while the field induced in metallic conductors persisted much longer. The EM61 receiver coils measured the intensity of the vertical component of the secondary magnetic field over a single time gate.

2.1.2 The EM61 coil assembly used for this investigation was composed of 0.5-meter coils. This coil assembly was a custom-built, scaled-down version of the standard 1-meter EM61 coils. Two coaxial square coils, 0.5-meter on a side, were mounted 40 centimeters (cm) apart on wheels. The planes of the coils were moved parallel to the surface of the ground with the lower coil about 30 cm above the ground. The smaller coils were designed to provide improved resolution and detection of shallower targets. However, deeper targets may not have been detected because the smaller transmitter coil generated a weaker primary magnetic field and the resulting secondary field induced less voltage in the smaller receiver coils. Figure 2.1 illustrates the EM61 with the 0.5-meter coil in use during the Fort Carson test demonstration.

2.1.3 The EM61 employed a bipolar, rectangular current with a 50% duty cycle, and a repetition rate of 75 Hertz (Hz). In other words, the transmitter turned on for 3.3 milliseconds (ms), turned off for 3.3 ms, turned on with reverse polarity for 3.3 ms, and turned off for another 3.3 ms. The standard EM61 integrates the voltage induced in each coil from 0.370 ms to 0.870 ms after the transmitter is turned off. In order to partly

FIGURE 2-1

EM61 WITH 0.5-METER COIL IN USE AT FORT CARSON

compensate for the decreased sensitivity of the 0.5-meter coil, the measured time gate was advanced to 0.180 ms to 0.220 ms after the transmitter was turned off for this investigation. Additional information on the theory and operation of the EM61 can be found in the Operator's Manual (Geonics, March 1995).

2.2 EM61-3D

2.2.1 Parsons ES also utilized the Geonics EM61-3D, a prototype three-component TDEM instrument, for the test demonstrations at Fort A.P. Hill and Fort Carson. The EM61-3D was a modified version of the Protem 47D (Geonics, October 1994) with a coil assembly resembling that of the standard EM61. The system consisted of a receiver, transmitter, and power supply mounted on a backpack; a hand-held controller; and the towed coil assembly. The transmitter coil was the standard 1-meter square EM61 coil. Three orthogonal, circular coils, which averaged approximately 0.5-

meter in diameter, were mounted within the transmitter coil. Figure 2.2 illustrates the EM61-3D in use during the Fort Carson test demonstration.

FIGURE 2-2

EM61-3D IN USE AT FORT CARSON

2.2.2 The EM61-3D measured the decay of the secondary magnetic field at 20 geometrically-spaced time gates in the three orthogonal directions. The instrument recorded a full set of 60 measurements every 0.4 second. At the 7.5-Hz repetition rate, the time gates ranged from 0.320 ms to 31.29 ms. At the 30-Hz rate, the time gates ranged from 0.328 ms to 8.06 ms. The time gates for the EM61-3D at both the 7.5- and 30-Hz repetition rates are listed in Table 2.1. A faster repetition rate resulted in a shorter measurable time-decay curve and a greater number of decay curves that were *stacked* to reduce sporadic noise. At the 7.5 Hz rate, three transmitter waveforms were averaged to produce a single reading. At the 30-Hz rate, 12 cycles were averaged.

TABLE 2.1
EM61-3D TIME GATE LOCATIONS

Gate	7.5 Hz, ms			30 Hz, ms		
	Start	Center	Width	Start	Center	Width
1	.320	.353	.065	.320	.328	.256
2	.385	.428	.085	.336	.347	.261
3	.470	.525	.110	.358	.371	.268
4	.580	.648	.135	.385	.402	.274
5	.715	.803	.175	.419	.441	.284
6	.890	1.003	.225	.463	.491	.296
7	1.115	1.258	.285	.519	.554	.311
8	1.400	1.583	.365	.590	.636	.331
9	1.765	1.998	.465	.681	.739	.356
10	2.230	2.525	.590	.798	.871	.388
11	2.820	3.198	.755	.945	1.039	.429
12	3.575	4.055	.960	1.134	1.254	.480
13	4.535	5.148	1.225	1.374	1.527	.546
14	5.760	6.543	1.565	1.680	1.876	.631
15	7.325	8.323	1.995	2.071	2.321	.739
16	9.320	10.590	2.545	2.570	2.888	.876
17	11.870	13.490	3.250	3.206	3.613	1.053
18	15.120	17.190	4.145	4.019	4.537	1.276
19	19.260	21.900	5.285	5.055	5.715	1.561
20	24.550	27.920	6.740	6.376	7.218	1.925
End of 20	31.290			8.061		

Notes:
All times are expressed in milliseconds (ms).
Table is based on Geonics (October 1994).
Time gates are listed for the 7.5- and 30-Hz repetition times.

SECTION THREE

ACQUISITION OF DATA

3.1 DESCRIPTION OF DATA ACQUISITION PROCESS

3.1.1 EM61

3.1.1.1 The EM61 surveys with the 0.5-meter coils were conducted along north-south lines with a 0.5-meter spacing. Station spacing along each line was approximately 0.2-meter, as measured by a calibrated survey wheel. Survey lines were marked by tape measures and traffic cones. The EM61 data logger recorded the voltage induced in the upper and lower coils at each measurement location. Data points were time-stamped using the internal clock of the datalogger, which was synchronized with the laser tracking system at the beginning of each data collection event (approximately every 1.5 hour).

3.1.1.2 A tracking prism was mounted on the 0.5-meter coils of the EM61, as shown in Appendix A. Parsons ES did not use the laser tracking data collected by WES to determine the coordinates of the data points collected with the EM61. Rather, the survey lines were marked by traffic cones. When the operator was headed north, the traffic cones were positioned at 50N and 100N. When the operator was headed south, the traffic cones were positioned at 50N and 0N. Depending on the direction of travel, an additional cone was placed at about -5N or 105N to establish a line of sight to the end of the survey line. The distance along each survey line was measured by a survey wheel calibrated to the ground conditions of the site. The measured distances were registered to the actual end of each line (usually 0N or 100N) by linearly stretching or compressing the position of the data along each line.

3.1.2 EM61-3D

3.1.2.1 The EM61-3D surveys were conducted along north-south lines with a 1-meter spacing. Measurements were taken at 0.4 second intervals while the operator walked along lines guided by tape measures and cones. The EM61-3D receiver recorded

the voltage induced in three orthogonal coils at each measurement location. The survey was normally conducted at the 7.5-Hz repetition rate, although some additional surveying was conducted at the 30-Hz rate.

3.1.2.2 Positioning control was conducted with the Leica laser tracking system provided and operated by WES. A tracking prism was mounted on the EM61-3D, as shown in Appendix A. Synchronization between the EM61-3D and the tracking system was accomplished as follows. Parsons ES signaled via radio the start time of each data collection event. WES recorded this time, which corresponded to the time that the first data point was collected. The EM61-3D utilized an extremely accurate internal clock which maintained relative time based on the sample interval of 0.400 second. Parsons ES again signaled WES at the end of the data collection event. The laser tracking time generally agreed with the relative EM61-3D time to within 1 or 2 seconds. The small time difference was attributed to rounding errors in reading the computer clock to the nearest 1 second.

3.2 FORT A.P. HILL DATA ACQUISITION

3.2.1 Parsons ES conducted TDEM surveys at Fort A.P. Hill, Virginia between September 30 and October 4, 1996. The TDEM surveys occurred at two test sites called Firing Point 20 and Firing Point 22. Parsons ES mobilized the following personnel to conduct this field effort: Scott Sauchuk (team leader), Josh Bowers, Sean Buckley, Beatrice Bidwell, and Randall Patrick. Parsons ES personnel arrived on-site at 9:30 am on September 30, 1996 and met with the test director, Ms. Vivian George of Walcoff. The sequence of the areas surveyed was determined by the test director and the test plan. Mr. Charles Hahn of WES was responsible for the operation of the laser tracking system. Personnel from the Night Vision Laboratory supervised the setup and administration of the site.

3.2.2 The EM61 surveys with the 0.5-meter coils were conducted within Firing Point 22 between September 30 and October 2, 1996. The EM61 surveys at Firing Point 22 included the following, in chronological order: the red, blue, yellow, and orange side bars; the center square (15E-45E; 95E-120E; 125E-145E); and a repeat of the orange, blue, red, and yellow side bars.

3.2.3 The EM61 surveys with the 0.5-meter coils were conducted within Firing Point 20 between October 2 and October 4, 1996. The EM61 surveys at Firing Point 20 included the following, in chronological order: the red, blue, yellow, and orange side bars; the center square (15E-90E); and a repeat of the orange, blue, red, and yellow side bars.

3.2.4 The EM61-3D surveys were conducted within Firing Point 20 between October 1 and October 2, 1996. The EM61-3D surveys at Firing Point 20 included the following, in chronological order: the blue, yellow, and orange side bars; the center square (15E-90E); a repeat of the orange, blue, and yellow side bars; the red calibration lane; the center square (91E-115E); and a second repeat of the orange, blue, and yellow side bars and the red calibration lane.

3.2.5 The EM61-3D surveys were conducted within Firing Point 22 between October 2 and October 4, 1996. The EM61-3D surveys at Firing Point 22 included the following in chronological order: the red, blue, and yellow side bars; part of the center square (15E-21E); the orange side bar; the remainder of the center square (22E-45E; 95E-120E); and a repeat of the orange, blue, yellow, and red side bars.

3.2.6 After completing the required amount of surveying, Parsons ES collected additional data within the side bars of Firing Point 22 using the 30-Hz repetition rate. These measurements recorded the decay of the secondary field from 320 μs to 7.821 ms after the transmitter was turned off. Additional data was collected in the blue, red, yellow, and orange side bars using the 30-Hz repetition rate.

3.2.7 After completing the required TDEM surveys and conducting the additional work, Parsons ES departed Fort A.P. Hill at 1300 on October 4, 1996. In summary, all of the equipment performed to a satisfactory level and the data collection effort occurred within the proper time frame.

3.3 FORT CARSON DATA ACQUISITION

3.3.1 Parsons ES conducted TDEM surveys at Fort Carson, Colorado between October 21 and October 25, 1996. The TDEM surveys were conducted at the Seabee and

Turkey Creek sites. The following employees of Parsons ES arrived at Range Control on Monday, October 21, 1996 at 7:30 am: Scott Sauchuk (team leader), Josh Bowers, Greg Van, Beatrice Bidwell, and Sean Buckley. Parsons ES personnel were joined by the test director, Dr. Thomas Altshuler of the IDA and the field crew from WES. WES was responsible for the setup of the test sites and tracking of the UXO sensors with a laser positioning system. After securing vehicle passes for Fort Carson, an organizational meeting with all parties was held at Range Control.

3.3.2 The required EM61 surveys with the 0.5-meter coils were conducted at the Seabee site between October 21 and October 23, 1996. The required EM61 surveys with the 0.5-meter coils were conducted at the Turkey Creek site between October 23 and October 24, 1996. The first step at each site was to demonstrate that the EM61 could detect a *stressing target* (Red-7) on line 8E. Then, the following areas were surveyed at each site: the blue, yellow, and orange side bars; the center square (15E to 90E); and the side bars again. After completing the required surveying, Parsons ES returned to the Seabee site on October 25, 1996 to cover additional area in the center square from 90E to 115E with the 0.5-meter EM61.

3.3.3 The EM61-3D surveys were conducted at the Turkey Creek site between October 21 and October 23, 1996. The EM61-3D surveys were conducted at the Seabee site between October 23 and October 24, 1996. EM61-3D surveys were not conducted on October 25, 1996. At the Turkey Creek Site, data was collected over the stressing targets, downloaded, and plotted. Preliminary inspection of the data showed that the EM61-3D detected the applicable stressing target (Red-7) on line 8E. At each site, in accordance with the Work Plan, the following areas were surveyed: the side bars (0E-5E, blue side bar; 11E-14E, yellow side bar; 120E-125E, orange side bar), the center square (15E to 90E), and the side bars again.

3.3.4 After completing the required amount of EM61-3D surveying, Parsons ES collected additional data with the EM61-3D at the Seabee Site. The remainder of the center square from 90E to 120E was surveyed. Then, data was collected at the 30-Hz repetition rate within all side bars and from 15E to 50E in the center square. These measurements recorded the decay of the secondary field from 320 μs to 7.821 ms after the transmitter was turned off. Occasionally, the tracking system would lose lock on the EM sensor due to obstructions between the electronic distance meter and the tracking

prism. For this reason, limited data gaps exist in the EM61-3D data. These limited EM61-3D data gaps are listed in Table 3.1.

3.3.5 Parsons ES began to demobilize at 10:30 am on Friday, October 25, 1996. In summary, all of the equipment performed to a satisfactory level and the data collection effort occurred within the proper time frame.

TABLE 3.1
DATA GAPS, EM61-3D, FORT CARSON

Data File	Line(s)	Time of Data Gap (seconds)		
		Start	End	Duration
3DSB.DAT (Seabee Site)	15-16E	1426.0	1439.6	13.6
	93-94E	79182.2	79193.8	11.6
3DSB_30.DAT (Seabee Site, 30-Hz)	16-17E	1562.8	1576.8	14.0
3DTC.DAT (Turkey Creek Site)	3E	361.2	372.8	11.6
	37-38E	9645.8	9693.4	47.6
	41-42E	10271.4	10295.4	24.0
	47-48E	11162.6	11179.8	17.2
	49-50E	11460.6	11476.6	16.0
	51-52E	11773.0	11889.4	116.4
	53-54E	12154.6	12169.8	15.2
	54-55E	12309.4	12319.8	10.4
	55-56E	12439.4	12459.0	19.6
	57-58E	20097.4	20121.8	24.4
	67-68E	22070.8	22140.0	69.2
	0E	85508.0	85522.0	14.0

Notes:
Time is reported relative to the first data point collected in the file.
The duration of the gap is not proportional to the amount of missing EM data.
Gaps often occurred outside of the test grid and while the instrument was stationary.

SECTION FOUR

PRESENTATION AND FORMAT OF ELECTRONIC DATA

4.1 ELECTRONIC DATA

4.1.1 All measurements reported as part of this investigation are raw, unprocessed data. Processing was conducted only to calculate the local coordinates of the data points and to reformat the data. Computer programs were written to: (1) register the EM61 0.5-meter data to the actual end of each line; (2) merge the laser tracking data with the EM61-3D data; and (3) reformat the data to satisfy the requirements of the Test Plan.

4.1.2 Electronic copies of the data collected during this program were delivered under separate cover to Dr. Ernesto Cespedes (WES) and Ms. Vivian George (Walcoff). The complete data set was provided on a single 100-Mb Zip disk in Background Standard Format, as specified in the Test Plan. The information was provided as uncompressed ASCII files, occupying nearly 90 Mb of disk space.

4.1.3 The data collected at Fort A.P. Hill are located in the APHILL subdirectory and consist of the following data and header files:

- 61FP20.DAT, 61FP20.HDR (EM61 with 0.5-m coil, Firing Point 20);
- 61FP22.DAT, 61FP22.HDR (EM61 with 0.5-m coil, Firing Point 22);
- 3DFP20.DAT, 3DFP20.HDR (EM61-3D, Firing Point 20);
- 3DFP22.DAT, 3DFP22.HDR (EM61-3D, Firing Point 22); and
- 3DFP22B.DAT, 3DFP22B.HDR (EM61-3D, 30-Hz, Firing Point 22).

4.1.4 The data collected at Fort Carson are located in the CARSON subdirectory and consist of the following files:

- 61SB.DAT, 61SB.HDR (EM61 with 0.5-m coil, Seabee Site);
- 61TC.DAT, 61TC.HDR (EM61 with 0.5-m coil, Turkey Creek Site);
- 3DSB.DAT, 3DSB.HDR (EM61-3D, Seabee Site);
- 3DSB_30.DAT, 3DSB_30.HDR (EM61-3D, 30-Hz, Seabee Site); and
- 3DTC.DAT, 3DTC.HDR (EM61-3D, Turkey Creek Site).

SECTION FIVE

SUMMARY

5.1 INTRODUCTION

5.1.1 Phase I of the study on the background characterization of the response of geophysical sensors for subsurface UXO detection focused on the acquisition of sensor data from two test sites. Since the analysis of the collected data will occur during Phase II of the study, this section of the report does not provide an interpretation of the results of the TDEM surveys conducted at Fort A.P. Hill, Virginia and Fort Carson, Colorado. Rather, this section presents information that may help the data interpreter to understand certain features of the data sets.

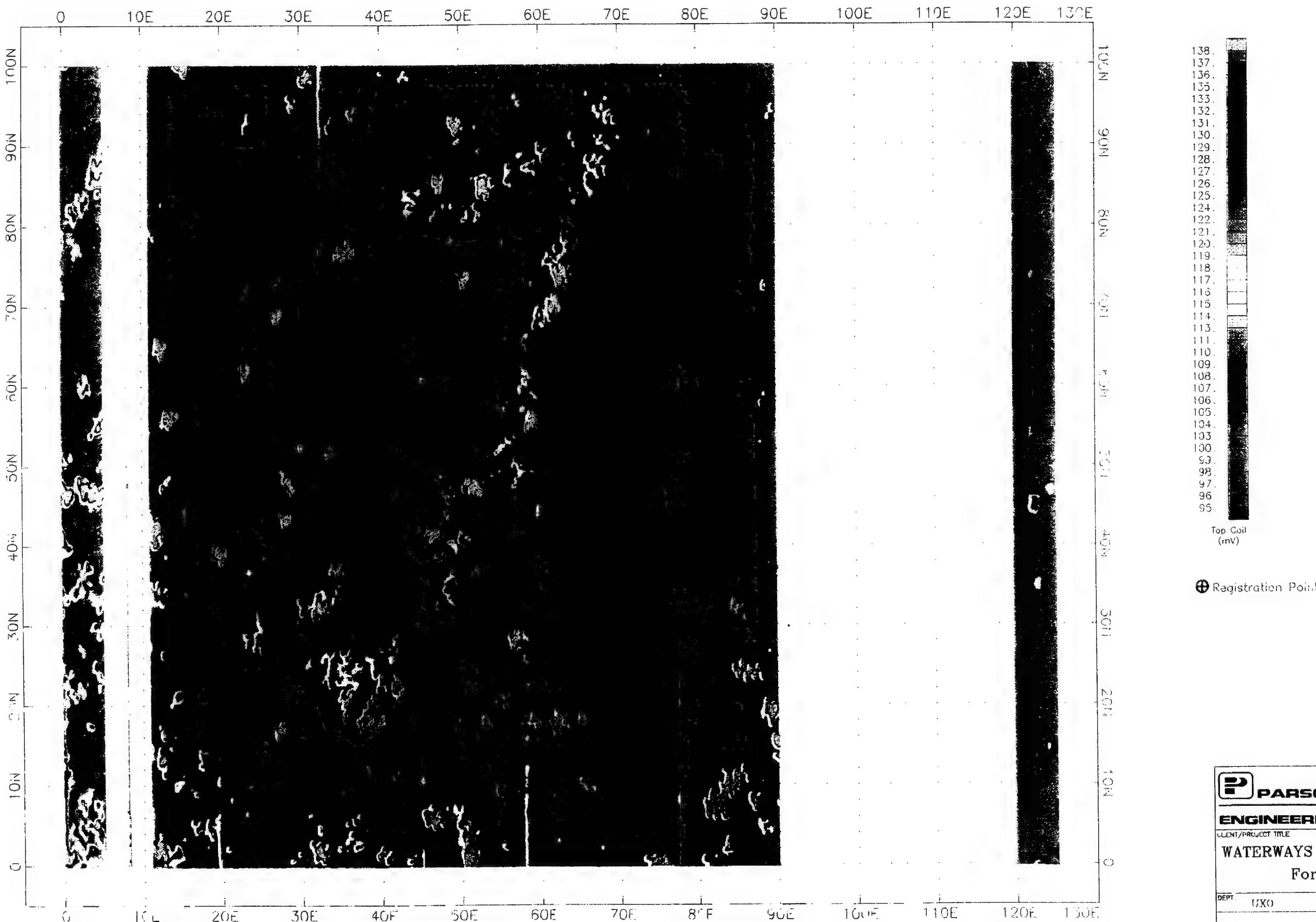
5.1.2 This section also presents several color maps produced by Parsons ES which illustrate representative data from each test site and UXO sensor. All figures were produced with the Geosoft mapping and processing system. The EM61 data was gridded with Geosoft's bi-directional gridding algorithm employing an Akima spline and a cell size of 0.125 meter (one-forth of the line spacing). The EM61-3D data was rasterized by Geosoft's minimum curvature gridding process with a cell size of 0.25 meter.

5.2 FORT A.P. HILL

5.2.1 EM61 0.5-meter

5.2.1.1 Figure 5.1 shows the response of the top coil of the EM61 0.5-meter coil at Firing Point 20, while Figure 5.2 shows the response at Firing Point 22. In general, due to the contrast in the number of EM anomalies, Firing Point 20 appeared to contain much more metallic clutter and debris than Firing Point 22.

5.2.1.2 Anomalous dips in the EM response were evident along the edge of the grid, particularly in Figure 5.2 (Firing Point 22). These low EM values always occurred at the beginning of an EM line. Unlike the standard EM61 with the 1-meter coils, the



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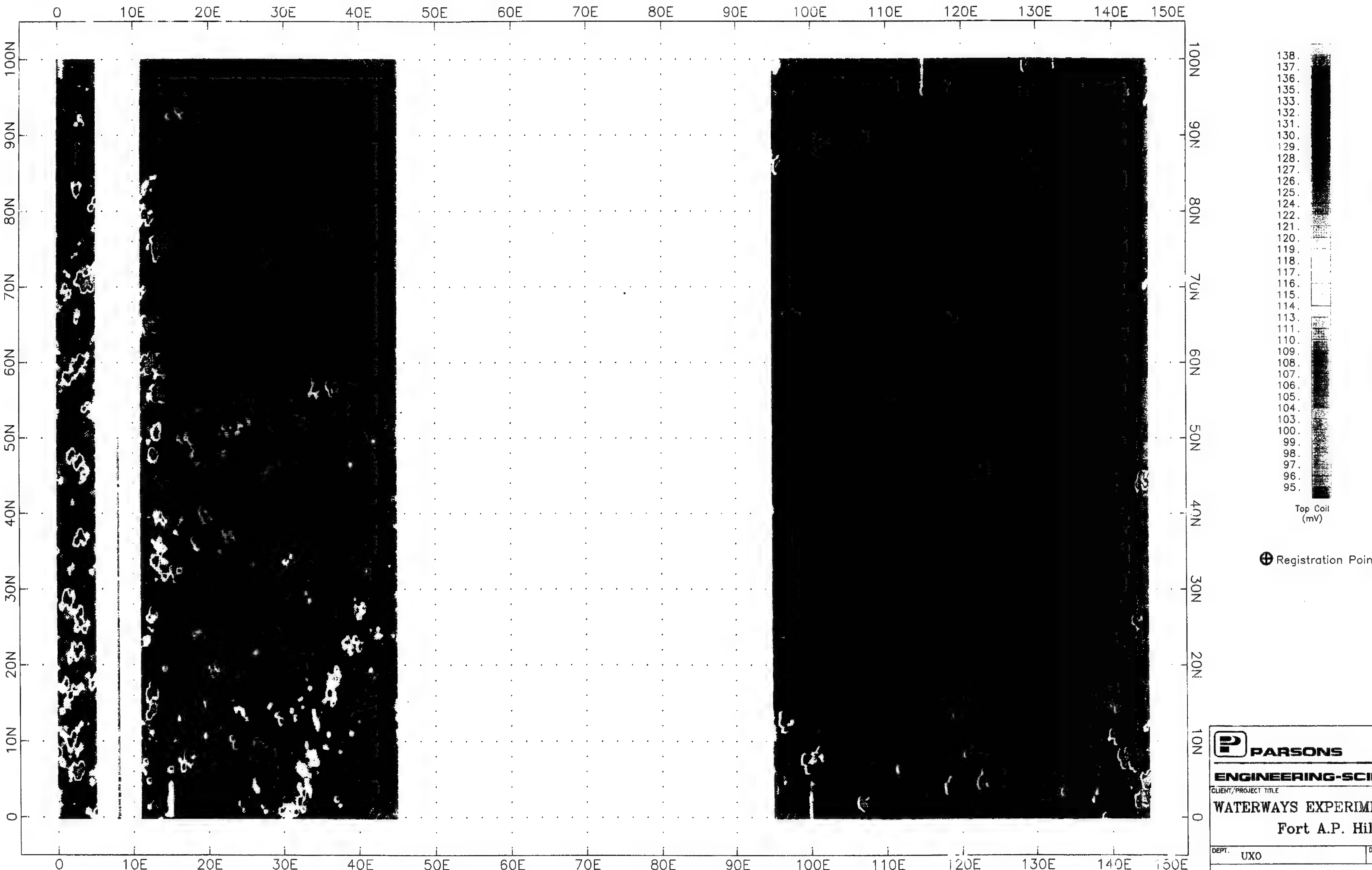
CLIENT/PROJECT TITLE WATERWAYS EXPERIMENT STATION Fort A.P. Hill	
DEPT. UXO	Dwg. No. 61fp20.plt
Figure 5-1 EM61 0.5–m, Firing Point 20	
SCALE 1 cm = 5 m	DATE 11 Oct. 1996 REV A



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ENGINEERING-SCIENCE, INC.

CLIENT/PROJECT TITLE

WATERWAYS EXPERIMENT STATION
Fort A.P. Hill

DEPT. UXO | Dwg. No.

Figure 5-2

EM61 0.5-m, Firing Point 22

SCALE 1 cm = 5 m | DATE 11 Oct. 1996 | REV A

EM61 with the 0.5-meter coils required about 2 seconds after depressing the record button to attain a stable reading. These anomalous values occurred when the operator began recording data before the EM61 had stabilized. This problem was recognized and generally eliminated during the surveying of Firing Point 20.

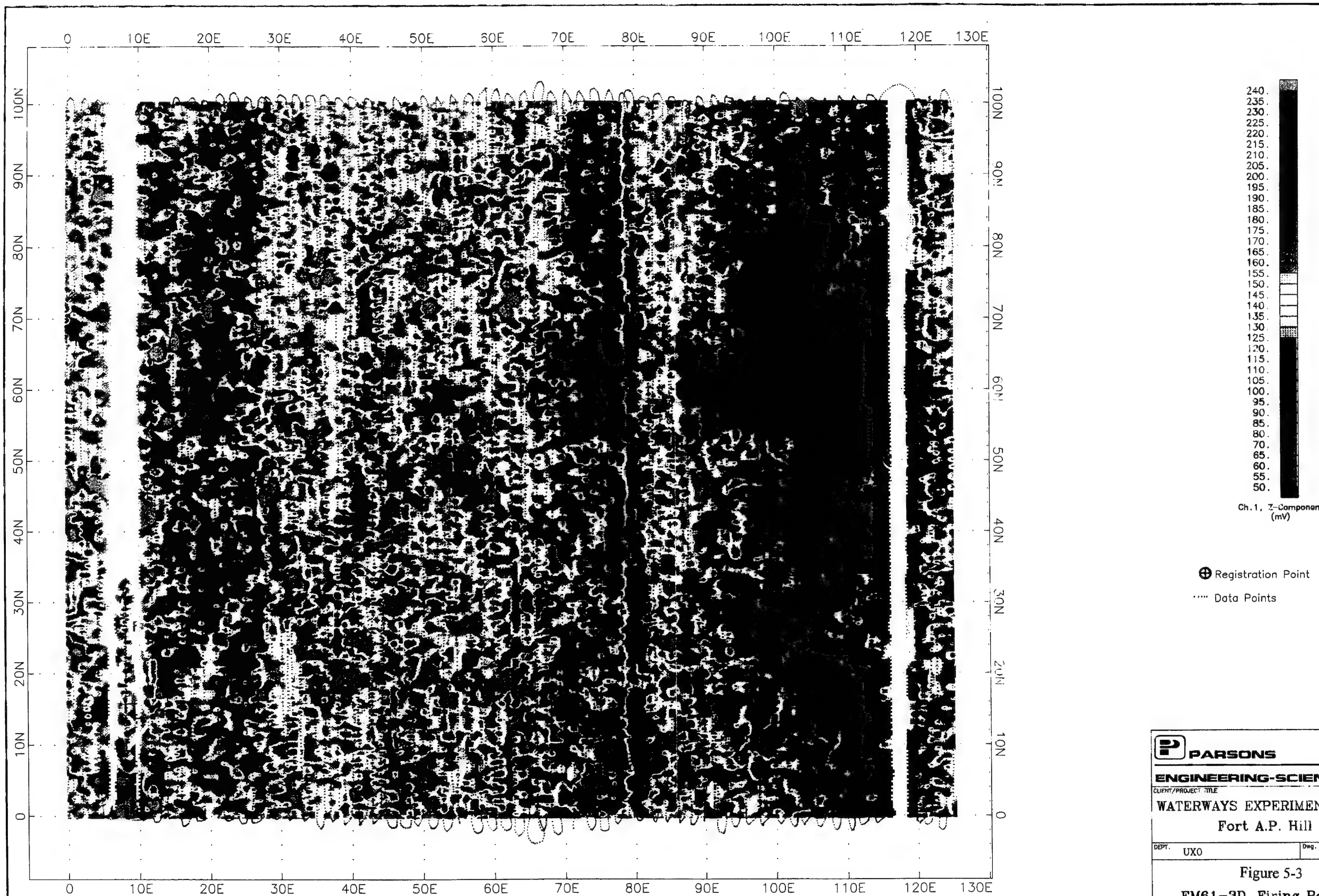
5.2.1.3 Figures 5.1 and 5.2 clearly show the TDEM response to the registration targets. Each registration point is marked on the figures. The targets associated with the registration points are: (1) a 4.875-inch diameter iron sphere, located 2 meters south of the marked registration point; and (2) an aluminum plate, 8 inches by 8 inches by 1 inch, located 2 meters north of the registration point. With the exception of the registration target at 105E, 62.5N at Firing Point 22, all other targets were clearly visible in the EM61 data collected with the 0.5-meter coil.

5.2.1.4 The electronics of the EM61 produced a slight delay between the voltage induced in the receiver coil and the associated response measured by the data logger. The effects of this output delay became evident by careful examination of the anomalies in Figures 5.1 and 5.2. Anomalies measured across adjacent lines, with the instrument traveling in opposite directions, were offset by a distance of approximately 0.5 to 1 meter and produced a zigzag appearance. At an acquisition speed of 1 meter per second, the output delay was between 0.25 and 0.5 second. Geonics has not documented the actual output delay time.

5.2.2 EM61-3D

5.2.2.1 Figures 5.3 and 5.4 of the EM61-3D data show the first measured time gate (0.320 to 0.385 ms) of the vertical component of the secondary magnetic field. The vertical, or Z, component was chosen because it peaks directly over the target and theoretically, has a greater amplitude than the horizontal components. The signal at the earliest time gate appeared to be representative of the other channels. These figures present unprocessed and unfiltered data.

5.2.2.2 Figure 5.3 shows the response of the EM61-3D at Firing Point 20, while Figure 5.4 shows the response of the EM61-3D at Firing Point 22. Consistent with the EM61 0.5-meter data, the former test site appeared more highly cluttered with metallic debris. However, the EM61-3D data was noisier than that of the EM61 0.5-meter.



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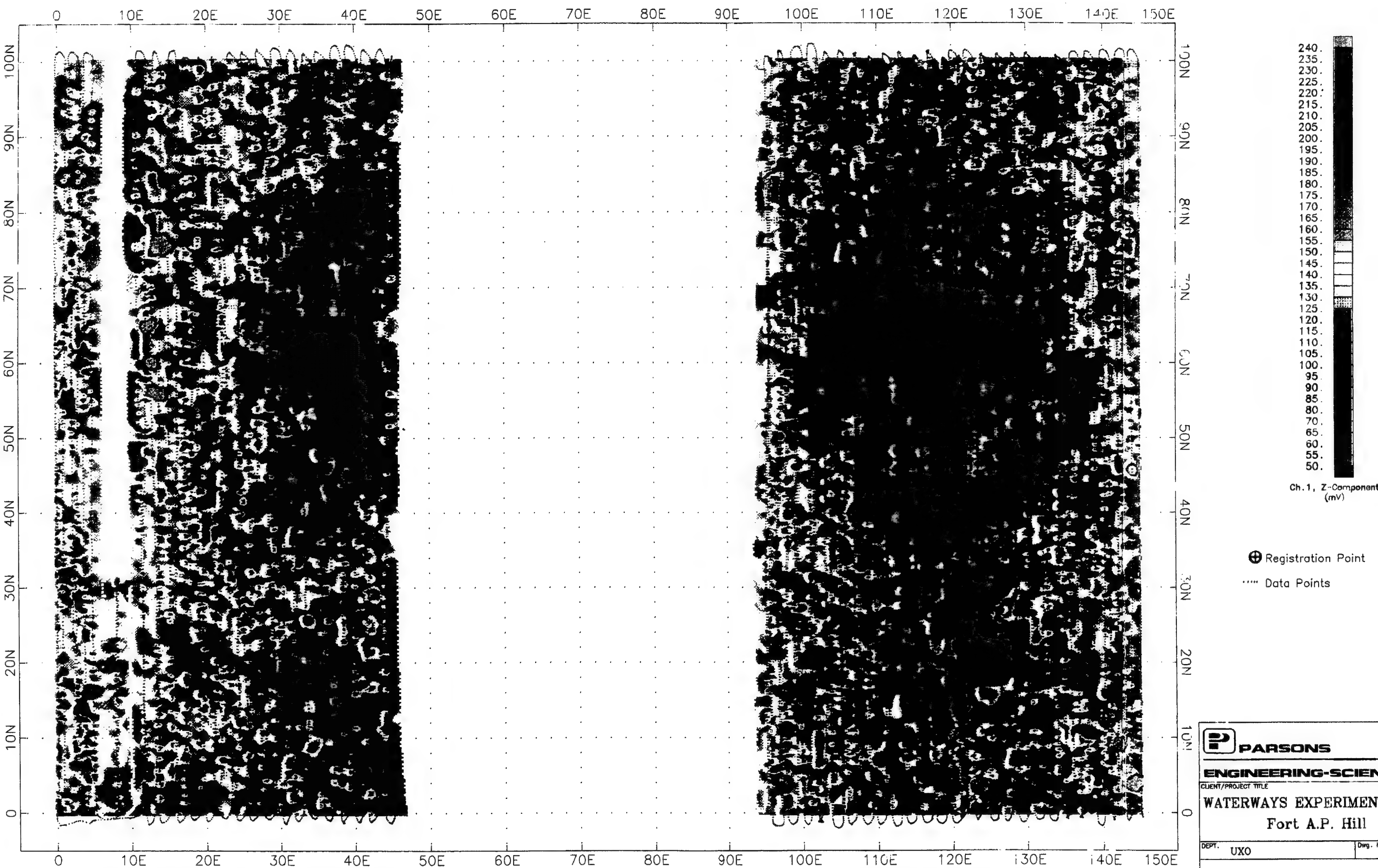
DEPT. UXO | Dwg. No. 3dfp20.plt

Figure 5-3
EM61-3D, Firing Point 20

SCALE 1 cm = 5 m | DATE 15 Oct. 1996 | REV A



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WATERWAYS EXPERIMENT STATION
Fort A.P. Hill

DEPT. UXO	Dwg. No. 3dfp22.plt

Figure 5-4
EM61–3D, Firing Point 22

SCALE 1 cm = 5 m	DATE 15 Oct. 1996	REV A

Although the larger amplitude anomalies were evident in both data sets, the smaller amplitude anomalies, including some of the registration targets, become lost in the background noise of the EM61-3D. Parsons ES did not attempt to identify the sources of or correct for this noise.

5.2.2.3 Geonics suggested two simple processing techniques to enhance the appearance of the data. First, each decay curve should be normalized by subtracting the value of the last channel from the remaining 19 channels. This will reduce the effects of low frequency noise (<1 Hz). Unfortunately, low frequency noise appeared to be a minor component, since this normalization procedure had little effect on the signal-to-noise ratio. Secondly, Geonics suggested applying a simple, spatial three-point smoothing filter to the profiles. This operation greatly improved the appearance of the data in profile form.

5.2.2.4 Striping or banding appeared in the data from Firing Point 20 (Figure 5.3). Since these features parallel the survey lines and no corresponding physical features were observed on the surface, the banding was likely due to instrument drift. At the start of a data collection event, a fresh battery would send 4.2 to 4.5 amps of current through the transmitter. At the end of the data collection event, the current would have typically dropped to 3.6 to 4.0 amps. The diminishing battery strength may have affected the EM61-3D output over the course of the survey.

5.2.2.5 Two sets of registration targets can be positively identified in the data sets (Firing Point 20 at 65E, 12.5N and Firing Point 22 at 140E, 12.5N). Some of the other registration targets may be present in the data, but are difficult to distinguish from the noise in the unprocessed records. These registration anomalies are displaced by about 1 meter from the true location of their corresponding targets.

5.2.2.6 Extremely low, negative readings were obtained with the EM61-3D within Firing Point 20 on line 73E (1N to 4N), line 75E (4N to 6N), and line 115E (52N-54N). At these locations, the response of the instrument apparently saturated at -3109 mV (first channel, z component). Apparently, these anomalies were not caused by subsurface objects because the anomalies were not observed on adjacent lines or in the EM61 data collected with the 0.5-meter coils. These anomalously low responses, flanked

by positive responses and characterized by an erratic decay curve, were likely caused by transient EM noise or instrument malfunction.

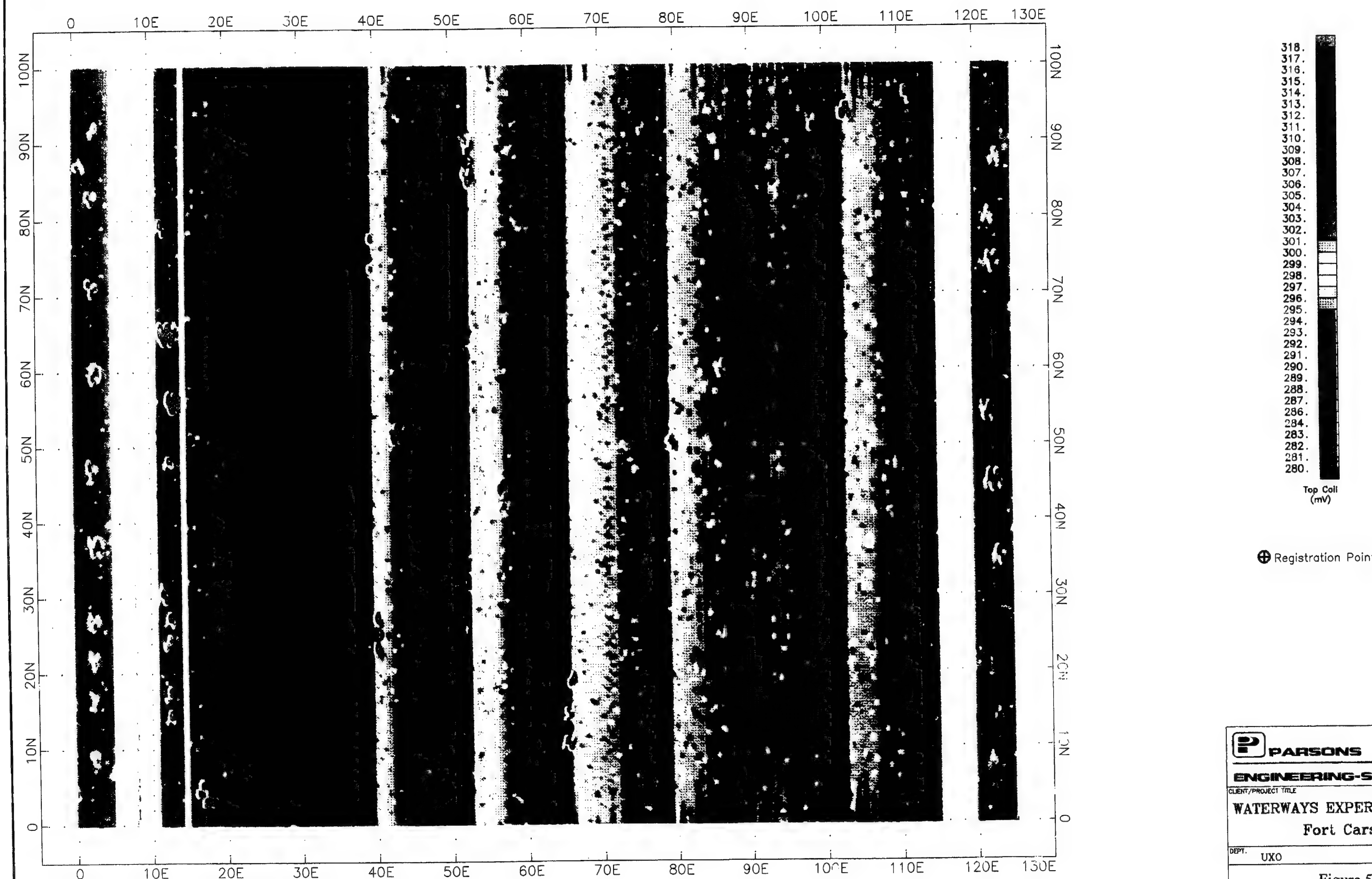
5.3 FORT CARSON

5.3.1 EM61 0.5-meter

5.3.1.1 Figures 5.5 and 5.6 show the response of the top coil of the EM61 at the Seabee and Turkey Creek sites, respectively. Aside from the side bars, which contain buried objects, both sites exhibit relatively quiet background conditions indicative of minimal metallic clutter.

5.3.1.2 The typical background readings obtained with the EM61 and the 0.5-meter coil were much higher at Fort Carson (about 300 mV) than at Fort A.P. Hill (about 100 mV). After all surveying was complete, the effects of a different tracking prism mount on the EM61 response were assessed. Background readings were taken in the same location with the prism in place and again after the prism had been removed. The top/bottom coil response with the prism in place was 294/-158 mV, and the response after the prism had been removed was 17/-165 mV. A large, steel bolt had been used to secure the prism to its wooden mount and this bolt was greatly affecting the response of the adjacent upper coil. However, the static shift caused by the tracking prism and its mount should not affect the interpretation of the data which relies on the relative intensity of anomalies above background levels.

5.3.1.3 The unprocessed EM61 data from Fort Carson clearly shows the effects of instrument drift as north-to-south banding. These bands were about 13 meters wide, which coincide with data collection events limited by the memory of the datalogger. Recharged batteries were always installed after downloading the datalogger. The instrument drift may be explained by the decreasing battery strength over the length of a data collection event. Another effect which was also observed at Fort A.P. Hill was the dip in the response at the beginning of the lines. As discussed earlier, these anomalous values occurred when the operator began recording data before the EM61 readings had stabilized.



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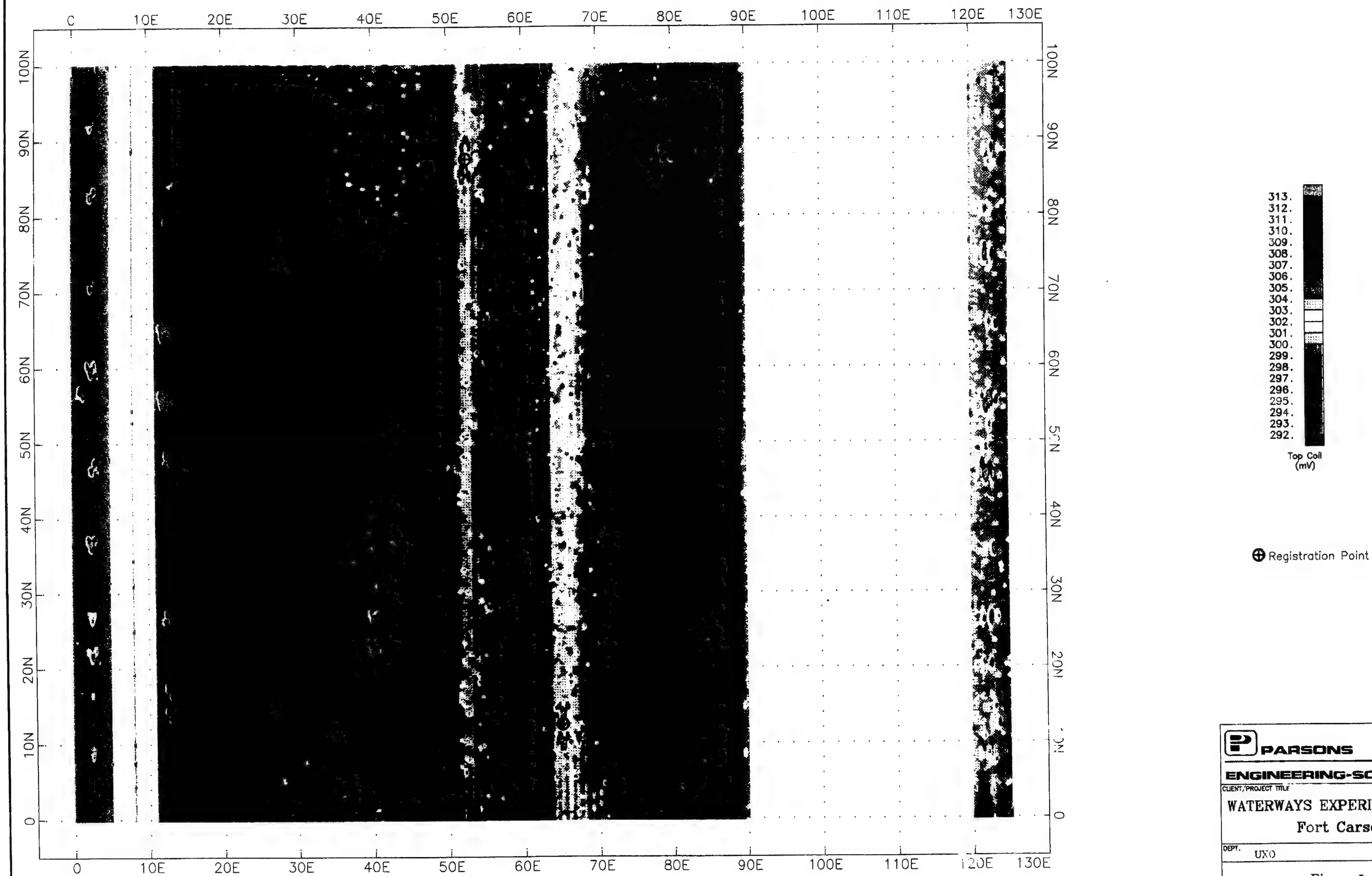
Fort Carson

DEPT. UXO | Dwg. No. 61sb.plt

Figure 5-5
EM61 0.5–m, Seabee Site

SCALE 1 cm = 5 m | DATE 28 Oct. 1996 | REV A



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CLIENT/PROJECT TITLE: WATERWAYS EXPERIMENT STATION Fort Carson	
DEPT. UXO	Dwg. No. 61tc.plt
Figure 5-6 EM61 0.5-m, Turkey Creek Site	
SCALE 1 cm = 5 m	DATE 29 Oct. 1996 / REV A

5.3.1.4 All ten sets of registration targets were detected by the EM61. The registration of these data was always within 0.5 meter of the true target location and often closer. As discussed earlier, the output delay of the EM61 produces anomalies with a zigzag shape. The true northing of each target is best estimated by averaging the position of the anomaly peak between adjacent survey lines. This procedure cancels the offset produced by the output delay time.

5.3.2 EM61-3D

5.3.2.1 Figure 5.7 shows the response of the earliest time gate of the vertical component measured by the EM61-3D at the Seabee site. Figure 5.8 shows the equivalent response measured at the Turkey Creek site. The typical background level of the EM61-3D measured at Fort Carson was comparable to that measured at Fort A.P. Hill. In order to facilitate comparison of results, the same color scale bar was used for all 7.5-Hz EM61-3D figures (50 to 240 mV in 5 mV increments).

5.3.2.2 Although the more intense anomalies were observed in both data sets, the EM61-3D data was noisier than the EM61 0.5-meter data. Some banding, due to instrument drift, was also evident.

5.3.2.3 Most of the registration targets appeared in the data. As expected, the EM61-3D recorded the greatest response when the instrument passed directly over the registration targets. The registration points at 40E, 25N and 65E, 12.5N at both sites produced the strongest response. A weak response, or no response at all, was observed over the other targets which were located in between survey lines (27.5E, 52.5E, and 77.5E). The registration anomalies were located within 0.5-meter of their corresponding targets, which provided an assessment of the accuracy of the positioning system.

5.3.2.4 Figure 5.9 shows the additional data collected with the EM61-3D at the Seabee site using the 30-Hz repetition rate. The fifth channel of the vertical component is displayed. This time gate, corresponding to a center time of 0.440 ms, appeared to exhibit less noise than many other channels. The 30-Hz data was clearly less noisy than the 7.5-Hz data. One explanation was that four times as many decay curves were averaged to obtain a single 30-Hz measurement.

SECTION SIX

REFERENCES

6.1 REFERENCES

Geonics Ltd., October 1994, *Protem 47D Operating Manual*, Mississauga, Ontario.

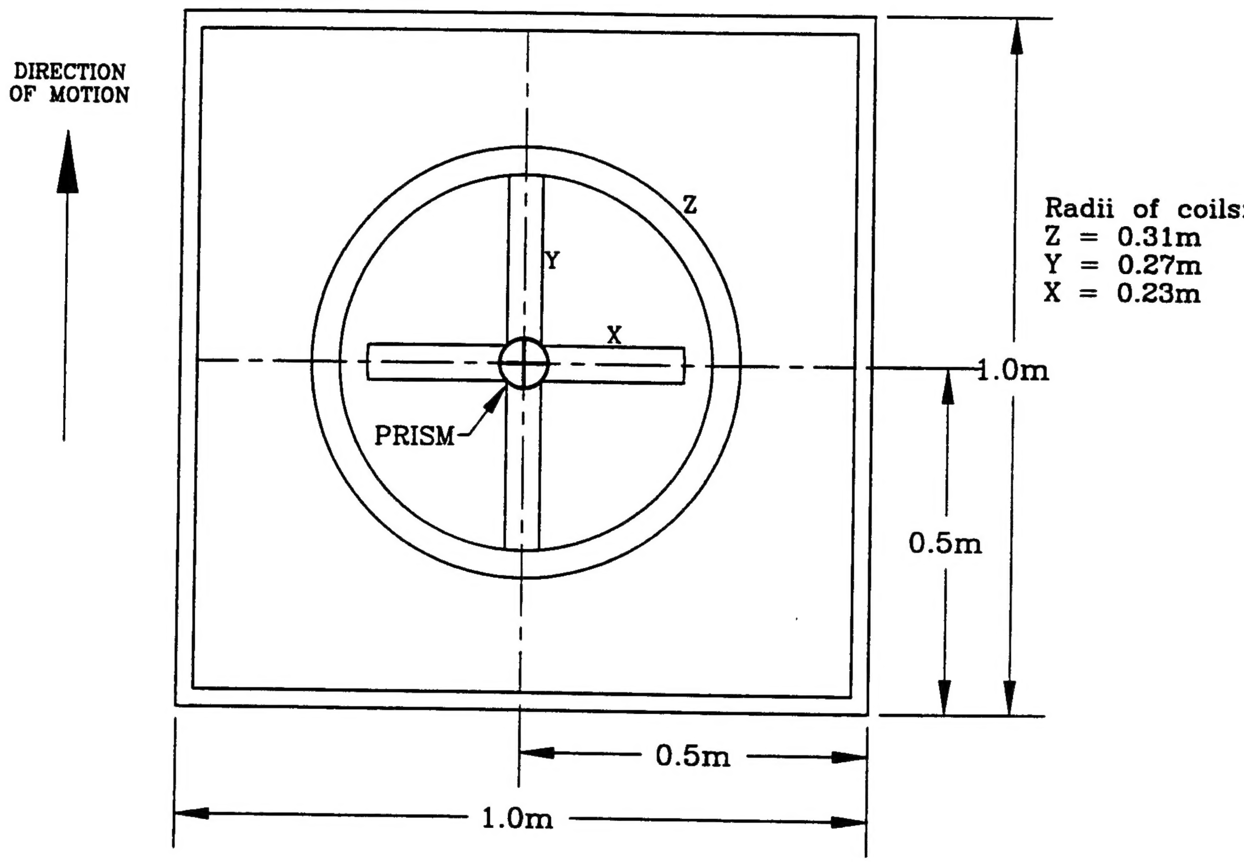
Geonics Ltd., March 1995, *EM61 High Sensitivity Metal Detector, Operating Manual,* Mississauga, Ontario.

APPENDIX A

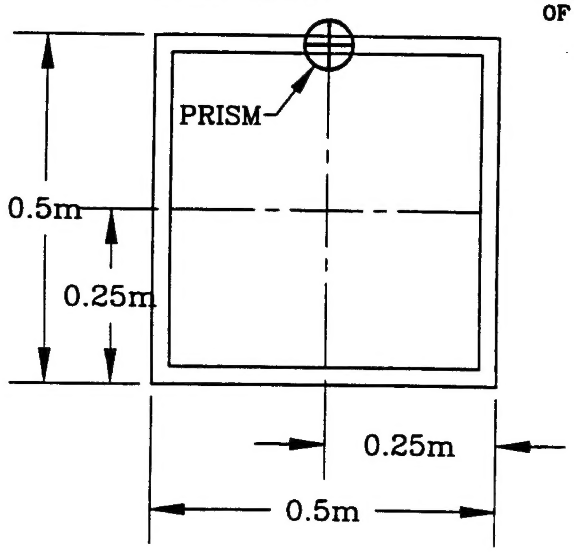
TRACKING PRISM MOUNTED ON 0.5-METER COILS OF THE EM61

APPENDIX A.
Location of Tracking Prisms on EM Coils

EM61–3D, Fort A.P. Hill and Fort Carson
Plan View:

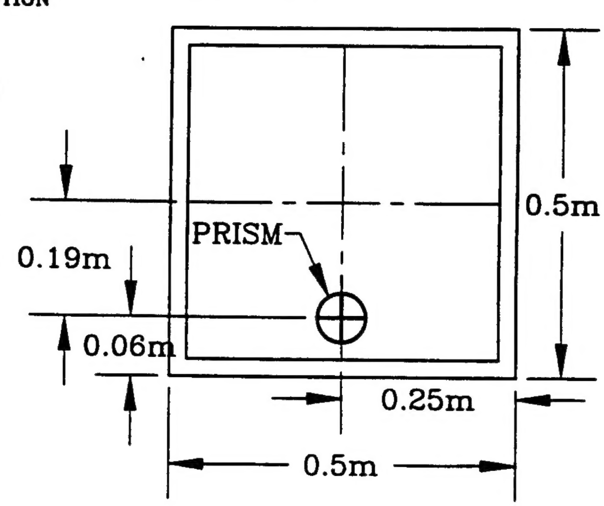


EM61, 0.5m Coil
Fort A.P. Hill
Plan View:



DIRECTION
OF MOTION

EM61, 0.5m
Fort Carson
Plan View:



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